BIOREGENERATIVE LIFE SUPPORT SYSTEMS

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Space research with manned missions demands a high amount of technical efforts. Space is namely a “lethal environment” for terrestrial organisms, i. e., that already the survival of extremely short time spans is impossible without complicated protective mechanisms which eliminate the hazardous space condititons. These are an extremely reduced pessure, drastical temperature alterations, near zero gravity, lack of circadian or seasonal rhythms and totally new radiation as well as energetic particle spectra. The latter, in particular, are determined by the so-called space weather conditions. In principle, humans can “artificially adapt” to those conditions with the help of technique constructing protective habitats providing a supply with oxygen, water and food. They are called “Life Support Systems” (LSS). The first step in this context is the creation of an “artificial living space” which protects from from all factors which endanger life. This is the so-called “Protective Component” of a LSS. The second is a “Sustaining Component” which implements environmental conditions which are similar to those on Earth. It is, in any case, coupled with a “Waste Management Component” which eliminates all metabolic and respitatory end products and other wastes. A LSS can be constructed in two ways. The first is the “Alimentary System” in which all substances necessary for survival are imported: oxygen, water and food. The wastes are stored and removed from time to time. This can be realized relatively safe and reliable, is technically practicable but it is in any case not “economical”. The second possibility is the “Regenerative Life Support System” in which the regenerative processes can be either chemical, physical or coupled. These sytems are, however, not able to produce food. So, they are no practicable solution for extreme lomg-term missions like human settlement in a Lunar or Martian base. The only solution of this problem is to utilize the tremendous regenerative potential of ecological systems, i. e., to use biological processes. *De facto* this can be only realized by the photosynthetic activity of green plants which convert with light energy carbon dioxide and water into carbohydrates and oxygen thus transforming cosmic energy into chemical energy (the life base of all heterotrophic organisms on Earth). This is the basic principle of a “Bioregenerative Life Support System” (BLSS). This term is essentially coupled with that of the “Artificial” or “Closed Ecological System” (CES) which may be implemented also in a “Partially Bioregenerative” or “Hybrid System” in which also physical and/or chemical components are present. When this concept is optimized solely as a series of artificial ecosystems form a fully bioregenerative LSS which represent an “artificial Biosphere” as a complete BLLS with a minimum of technical components. In the ideal case only cosmic (light) energy has to be imported to make the system operative. LSS may be seeen also under another aspect. An alimentary system is ever “open”, i. e. it demands the import of substances and energy and the export of wastes. In contrast, the ideal BLSS is “closed” and the only import is solar energy. A closed LSS can not be realized without biological components because a food production unit is essential to maintain the human habitat. This can be verified in the easiest way with higher plants which consume CO_2 in the process of photosynthesis and produce 0_2. The latter is utilied for athmosphere regeneration in the habitat. Urine, feces and excess CO_2 are recycled in a waste processor and recondensed water is added again to the stock. The resulting mineral end products are used in the food production unit as fertilizer. This concept of the predominant role of hiher useful plants as grain, potatoes, tomatoes etc. was taken over world-wide into the research and developent of BLSS. The U.S.A. and the former U.S.S.R. (somewhat reduced now Russia) play the leading role. Within the U.S.A. the “Advanced Life Support Research” has a long tradition and a spectacular example is the gigantic “Plant Growth Chamber” at Kennedy Space Center which, however, has a productivity to nourish almost one human being. In the USSR aleady in the sixties of the past century a real pioneer work was done with the so-called BIOS experiments which ended up in the highly successful BIOS-3 habitat with a volume of 350 m^3. For the nutrition and atmosphere regeneration of one human being 30 m^2 of culture area for useful plants was necessary. Within this system 2 to 3 crew members could be supplied to 95% for more than 2 years. Obviously NASA took over these basic principles and currently in Jonson Space Center in Houston a complex habitat is developed which resembles closely to BIOS-3. A series of smaller innovative projects like a “Salad Machine” and a “Biomass Production System” are funded by NASA. Japan goes a different way combining phytotrons for useful land plants with complicated physical-chemical regeneration components. This concept is realized in the impressing “Closed Ecology Experiment Facility” in Rokkasho but it is doubtful if this is really suitable for space applications. The serious disadvantage of all these projects is the fact that the used higher land plants are ever gravitropic and do not grow very well and do not form seeds under reduced gravity which is especially disastrous for crop production. Therefore, in Germany a totally different concept for BLSS was developed. The basic idea is to use aquatic organisms which are adapted since millions of years to reduced gravity on Earth. An experimental device was develped, the so-called „Closed Equilibrated Biological Aquatic System“ (C.E.B.A.S.) which consists of a bioreactor for non-gravitropic edible water plants, a tank for aquatic animals (fishes, water snails), an ammonia oxidizing bacteria filter and a data acquisition/regulating unit. This C.E.B.A.S. showed biological stability in the ground laboratory for more than 13 months. A miniaturized space version, the C.E.B.A.S. MINI MODULE, was successfully tested in the space shuttle missions STS-89 and STS-90. The results demonstrated -amongst other findings- that the plants showed in comparison with the ground control an undisturbed growth and that the reproductive functions of the fishes and snails including embryonic development remained normal. The C.E.B.A.S. MINI MODULE will fly a third time in space in July 2002. The results of the space experiments do not demonstrate only that aquatic plants are highly suitable for BBLSS operated under reduced gravity but also that it will be possible to produce animal protein for human nutrition in aquaculture in space which cannot be realized with land animals by reasons of unsolvable waste management problems. For Earth applications numerous innovations evolved from the C.E.B.A.S. the most spectacular of which is an intensive aquaculture system for the combined production of animal and plant biomass,